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The effects of population growth on timber management and inventories in Virginia

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Abstract

Expanding human populations may have important effects on the availability of timber from private lands in the South. To examine the effects of development on timber supply, we compared the density of populations and various site variables with expert opinions on the future location of commercial timberland for a study site in Virginia. Population density is a significant predictor of commercial timberland and resulting probability equations provide a method for adjusting timber inventories. Findings indicate that the transition between rural and urban land use occurs where population density is between 20 and 70 people per square mile. Population effects reduce commercial inventories between 30 and 49% in the study area. © 1999 Elsevier Science B.V. All rights reserved.

1. Introduction

An expanding human population may have important implications for forest resources in the United States. As domestic and global populations grow, so grows demands for resource products and natural settings. Increasing production, in turn, may adversely affect the environmental and aesthetic quality of forests. At the same time, the expansion of residential and urban areas will likely reduce the amount of resources available for the production of goods and services (Marcin, 1993; Harris and DeForest, 1993). Over time, these concurrent impacts on both timber demand and timber supply could result in increasing market scarcity and continued upward pressure on timber prices. Additionally, expanding 'urban–rural interfaces,' as they are sometimes called, may hold implications for other resource values (Shands, 1991). For example, wildlife habitat may become more fragmented and otherwise less effective as an area becomes more populated. Managing forest fuel loads may also become increasingly problematic and forest fires are likely to be more difficult to fight and more costly as population density increases.

This study examines the potential effects of population growth on timber supply. In particular, we examine how expanding populations in a part of western

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Virginia may influence the management of forests and the eventual supply of timber from forest lands. We posit that increasing population density affects timber supply in two different ways. One is the conversion of forests from a timber-growing use to a residential or urban use. When this occurs, land will no longer be available for timber harvest or timber growing, though the transition may be coincident with some timber harvesting – so called 'real estate cuts'. A more subtle effect may be the reduced investment in timber production in areas of moderate population density as landowners anticipate continued population growth and changes in land uses. This perceived impermanence of land use may discourage active investment in timber production, thereby reducing future timber supply.

In this study, we examine the potential effects of population growth on timber production using a two-step approach. First, we compare expert opinions on where forests will not be managed as commercial timberland with population density in these areas, and test for a relationship between the two. Then, we use the relationship between population density and likely timber management to adjust timber inventories for population effects. The study provides insights into these important issues but, perhaps more importantly, offers some practical methods for assessing the effects of population growth on estimates of timberland area and timber inventories.

2. Study site

Our study site is Virginia's Thomas Jefferson Planning District shown in Fig. 1. This area is defined by five counties in the general vicinity of the city of Charlottesville: Albemarle, Fluvanna, Louisa, Greene, and Nelson. The area has the hilly topography characteristic of the Piedmont of the Appalachian Blue Ridge and a variety of forest types. The Oak-Hickory type predominates but significant areas of Loblolly-Shortleaf Pine and Oak-Pine types are also present (Thompson, 1992). Accordingly, hard hardwoods comprise the largest share of growing stock volumes, but soft hardwoods and pine also represent significant components of inventory.

3. Methods

3.1. Relationship between population density and commercial forestry

Physical measures of timberland may provide limited insights into whether or not forest land will actually be used for timber production. The first step of our analysis was therefore to define where lands were indeed likely to be managed for timber production. We asked county foresters familiar with the study

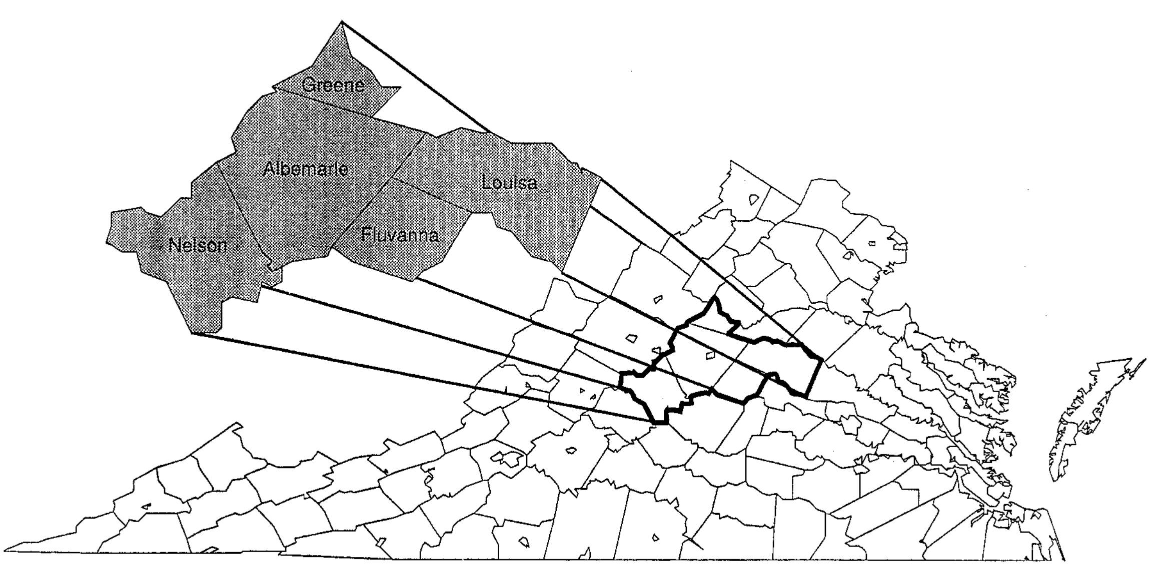

Fig. 1. Map of the study area.

site to map their opinion of where commercial forestry would and where it would not likely be practiced in the future. They further identified those areas that would not be managed due to some special site feature (not necessarily related to population and land use pressures) such as critical species habitats, proximity to water, or buffers. These maps were drawn at a 1 : 24 000 scale and were digitized and entered as a GIS map layer.

We then tested the relationship between this expert classification of potential commercial timberland (PCT) and several factors describing the accessibility and operability of the site and the population density of the area. That is, we posited that the probability of land (L) being labeled as PCT is given as:

$$\Pr(L = \mathrm{PCT}) = f(X_i) = 1 - F(g[X]) \qquad (1)$$

where F is a cumulative distribution function which depends on a function (g) of a vector of explanatory variables (X). We assumed that F had a logistic form which is a close approximation to the normal distribution. The resulting 'Logit' model has the following form:

$$\Pr(L = \mathrm{PCT}|X) = 1 - F(g[X]) = \frac{e^{-g(X)}}{1 + e^{-g(X)}} \qquad (2)$$

The vector X includes the following variables: the population density of the area (POP, people per square mile), site index (SI, height at age 50), slope (SLOPE%), and two dummy variables that define ease of access to the site (AC-EASY and AC-HARD). AC-EASY is equal to 1 where survey crews indicated that, while roads did not exist, they could be easily built; equal to zero otherwise. AC-HARD is equal to 1 if roads were deemed difficult or very difficult to build. The null case is defined where roads to the site already exist. Taken together, these variables describe the comparative advantage of each site for various land uses. To estimate the model, we define the functional form of g as follows:

$$g(X) = a + b_1 \underset{(-)}{\mathrm{POP}} + b_2 \underset{(-)}{\mathrm{SI}} + b_3 \underset{(+)}{\mathrm{SLOPE}} + b_4 \underset{(-)}{\mathrm{AC}}\text{-EASY} + b_5 \underset{(+)}{\mathrm{AC}}\text{-HARD} \qquad (3)$$

where the signs in parentheses indicate our expectations regarding the effect of the referenced variable on the probability of forest cover. We expect that increasing population density increases demand for non-forest land uses, that ease of operability (i.e., low slopes) also reduces the likelihood of forest cover, and that less accessible sites are more likely to be forested. We expect the effect of site index to be negative given that higher quality land may have comparative advantage for use in agriculture.

Previous studies have used similar models to examine the harvest choices of individual landowners. The earliest application (Binkley, 1981) addresses the effects of income, price, education, and costs on the decision to harvest timber. Subsequent studies (e.g., Dennis, 1990; Kuuluvainen and Salo, 1991) have used discrete choice methods to simultaneously address the decision to harvest and the quantity of the harvest. The present study is perhaps most closely related to Wear and Flamm's (1993) cross-sectional model of harvest choice in a single watershed. Their analysis uses site features (assuming constant delivered prices) to proxy for the costs of harvesting. The present study is distinct by virtue of its independent variable. The use of an expected land-use is an attempt to address long-run resource allocation.

To test this relationship, we examined the land use classification for US Forest Service permanent inventory plots located in the study area. Using these plots gave us access to several other descriptive variables and allowed us to subsequently estimate the implications of population density on standard measures of timberland area and timber inventories. We overlaid the plot locations through the GIS to assign a population density to each plot. We then screened the plots to define the subset of forest plots in private ownership without the aforementioned special features defined by local experts. We then defined L as a binary variable where those plots that were classified as PCT were assigned L=1; otherwise they were assigned L=0.

Plot observations were then used to estimate the Logit model defined by Eq. (2) using standard maximum likelihood estimation applied to individual survey plots.[1] To test for the effect of the independent

[1]This involves constructing the likelihood function based on the probabilities defined by Eqs. (2) and (3) and solving for coefficients that yield the highest likelihood that the model generated the data. We used the statistical package LIMDEP (Greene, 1992). Techniques are described in detail in Maddala (1983).

variables on probability that land would be commercial timberland we test the significance of the model as a whole using log likelihood ratio tests and for the significance of coefficients using t-statistics.

3.2. *Estimating the effects of population on forest area and timber inventories*

Eq. (2), in addition to being used to test our hypothesis about the effect of population on the potential for commercial forestry, also provides a way to predict the probability of commercial forestry as a function of population density and other variables at any location within the study area. Given that the fit of Eq. (2) is significant, then coefficient estimates and measures of the independent variables can be used to estimate the probability that land will be commercial timberland.

This estimated probability also defines the share of the forest area with this population density that would be expected to be commercial forest. To estimate the total effect of population density on timberland area then, we apply the probability of commercial forestry to the area represented by each permanent inventory plot in the study area using methods defined by Hardie and Parks (1991). In equation form:

$$E(\mathrm{CF}) = \sum_{i=1}^{n} A_i f(x_i) \tag{4}$$

where E(CF) is the expected total area of commercial forest in the study area, A_i the area expansion factor for plot i, x_i the population density at plot i, and n the number of plots in the area. We apply these estimates to all plots in the five-county study area to estimate total effects and calculate effects on a county by county basis as well. We used the same approach with inventory expansion factors to estimate the effect of population density on growing stock inventories in the area.

4. Data

The methods defined above require overlaying four sets of spatially referenced data: (1) expert opinion maps of where forests will and will not likely be managed as commercial forests; (2) US Census data on population density recorded at the block level; (3) US Forest Service inventory plots and their associated data; and (4) USGS land use categories.

4.1. *Expert opinion maps*

Expert opinions were developed by the field foresters at the county level who have considerable knowledge of forest ownership and production. Experts mapped their opinions directly onto maps at a 1 : 24 000 scale for Albemarle, Greene and Nelson counties. Boundaries were then digitized and stored as a map layer in the Arc-Info geographic information system.

4.2. *US Census population*

Census Tiger files were used to map population density (people per square mile). Density is defined for US Census blocks. Blocks are the smallest geographic units that the Census calculates statistics for.

4.3. *Forest inventory data*

Forest inventory plots measured in 1991 (Thompson, 1992; U.S.D.A. Forest Service, 1985) were then overlaid within the GIS. We recorded volume estimates and area and volume expansion factors from the inventory plot data base. We also recorded slope, site index, and access categories for each plot. Expert opinion observations and population density could then be assigned to each inventory plot by overlaying map layers.

4.4. *Land use*

We also used land use classification maps from the USGS to identify those plots that are in built-up urban areas.

5. Results

The logit model defined by Eqs. (2) and (3) was estimated using 94 forest survey plots. Of these 94 plots, 30 were identified as potential commercial forest. Coefficient estimates and standard error (Table 1) indicate that population density is negatively related to the probability of commercial forest

Table 1
Coefficient estimates of the logit model defined by Eqs. (2) and (3), using data from Albemarle, Greene, and Nelson counties. An asterisk indicates significance at the 5% level. The log likelihood ratio (LLR) for testing the overall significance of the model is also reported

Coefficient	Estimate	SE
Intercept	0.0617	1.5803
Pop	−0.0424	0.0133 *
Slope	0.0161	0.0158
Site	0.2076	0.2085
AC-EASY	−1.0528	0.6765
AC-HARD	2.0237	2.0623
LLR	30.96 *	
n=94		

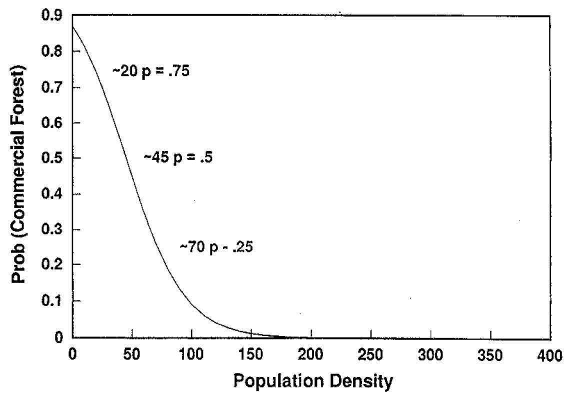

Fig. 2. The predicted probability that forest is commercial timberland as a function of population density.

(throughout this paper significance was tested at p=0.05). However, all other variables (slope, site index, and access categories) have insignificant coefficients. We also tested the significance of population density by estimating the logit model without the variable and constructing the log likelihood ratio statistic for the constrained model (chi-squared distribution with one degree of freedom). The calculated statistic (23.362) is greater than the critical value (3.841), so we again reject that the variable has no effect.

As all other variables are insignificant, we estimated a condensed model with only population density as an explanatory variable to apply the probability model to area and volume expansion factors using Eq. (4). For this model, the intercept was 1.9065, the population density coefficient was −0.0421, and both coefficients were significant. We tested the overall significance of both the original model and the condensed model using a log likelihood ratio test (chi-squared distribution, with degrees of freedom equal to the number of explanatory variables). For both models we reject no explanatory power (see Table 1).

To further examine the effects of population density on timber production, we plotted the probability of forest being commercial timberland as a function of population density. Fig. 2 shows the expected inverse relationship between population density and PCT. At a population density of 0, the probability of PCT is 0.82. The probability declines as population density increases and approaches zero as density reaches ca. 150 people per square mile (psm). The odds of being commercial forest land are roughly 50 : 50 at a population density of 45 people psm and the probability of commercial forestry is >0.75 at ca. 20 people psm.

The next step in the analysis was to estimate the predicted probability of commercial forestry for all survey plots in the Planning District as a whole. Fig. 3 shows the distribution of plots by probability values. Thirty percent of the plots have probability values of 0.8 or greater and 57% have probability values of 0.7 or greater. However, 25% of the plots have probability values that are <0.5, indicating a <50 : 50 chance of commercial forestry.

Area and volume expansion factors for all plots were then used to calculate the expected commercial

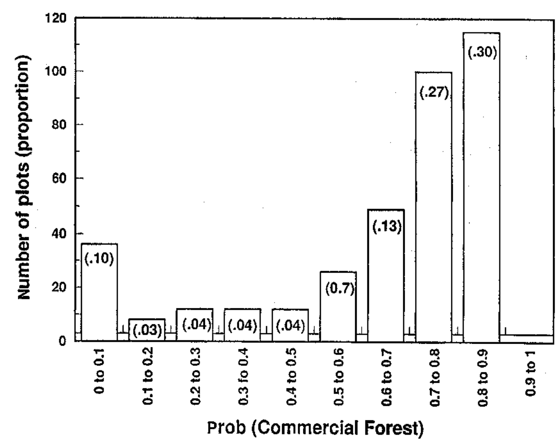

Fig. 3. Number (proportion) of inventory plots by the predicted probability that forest is commercial timberland.

Table 2
Area of timberland in the study area for the 1991 survey. Subsequent columns show the effects of (1) removing lands in public ownership, (2) removing lands classified as urban, and (3) reducing availability related to increasing population density

Area	Land area			
	1992 survey	Minus public	Minus urban	Minus pop. effect
	Acres			
Total	929 557	907 015	851 358	548 985
Albemarle	278 205	275 169	267 596	171 717
Fluvanna	137 348	136 358	107 064	65 167
Greene	53 599	52 472	52 472	26 173
Louisa	228 537	227 742	208 952	125 421
Nelson	231 868	215 274	215 274	160 508

forest area and associated growing stock inventories for each county in the study area. Projections of forest area are shown in Table 2. The first column in Table 2 lists the total forest area estimated by forest survey plots in the Planning District (929 557 acres). We next subtract the public lands from the area. This reduces total acreage by ca. 2.4% to a total of 907 015 acres. Nelson County has a disproportionately large share of the public forest land (ca. 7.2%) while Fluvanna has very little public forest land (ca. 0.7%). The area of land in urban land uses (USGS codes 10-17) is then excluded, removing another 5% of the forest area and leaving 851 358 acres. We then applied Eq. (4) to these remaining acres to calculate the effects of population density on the availability of rural private timberland.

Comparing columns three and four in Table 2 shows the total effect of population density on forest land availability. These are also charted in Fig. 4. Population effects reduce by an additional 32% the estimate of available forest land in the Thomas Jefferson Planning District . Removing urban and public lands and adjusting forest area for population effects results in a total reduction of available forest area by 41%. The effects are highest in percentage terms for Fluvanna and Greene counties (−52.6 and −51.2%, respectively) and least for Nelson County (−30.8%). The effects on growing stock inventories are shown in Table 3 and are similar to effects found for timberland area. Pine volume is reduced by the greatest amount (49%). The growing stock inventory of other softwoods is reduced by 38% from forest inventory values.

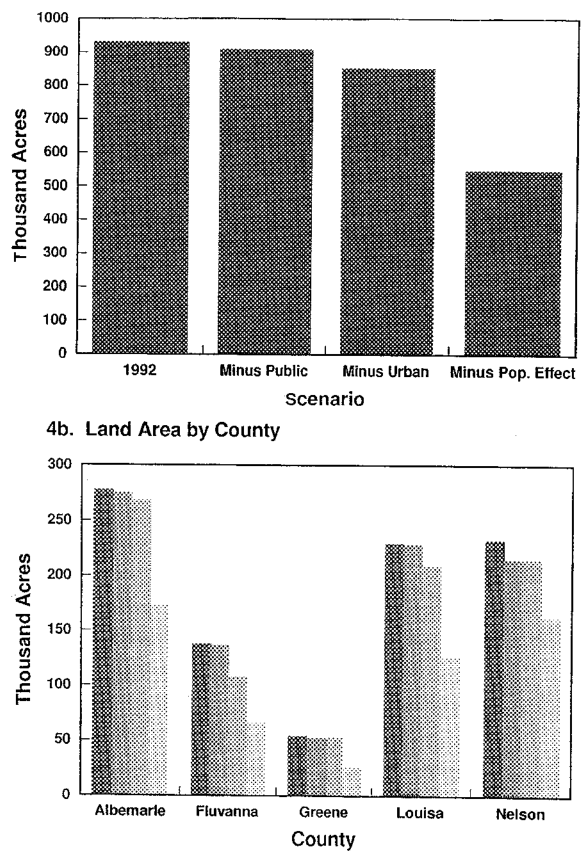

Fig. 4. Total timberland in the Thomas Jefferson Planning District: (1) defined by the 1992 inventory; (2) after screening public lands; (3) additional screening of urban lands; and (4) additional screening based on the predicted probability of commercial timberland.

Table 3
Growing stock volumes in the study area for the 1991 survey. Subsequent columns show the effects of (1) removing lands in public ownership, (2) removing lands classified as urban, and (3) reducing availability related to increasing population density

	1992 Survey	Minus public	Minus urban	Minus pop. effect
	Thousand cubic feet			
(a) Pine volume				
Total	300 149	289 577	257 904	154 439
Albemarle	76 035	76 035	67 394	42 217
Fluvanna	64 580	64 580	44 468	22 716
Greene	28 301	28 301	28 301	19 395
Louisa	96 042	96 042	93 122	51 902
Nelson	35 191	24 619	24 619	18 209
(b) Other softwood volume				
Total	42 038	41 570	40 748	25 994
Albemarle	16 416	16 416	15 955	7 372
Fluvanna	467	467	467	260
Greene	1 806	1 806	1 806	1 365
Louisa	4 928	4 928	4 567	3 016
Nelson	18 421	17 953	17 953	13 981
(c) Soft hardwood volume				
Total	431 076	411 474	396 438	259 772
Albemarle	119 620	119 620	119 620	81 411
Fluvanna	40 866	40 866	28 456	20 287
Greene	41 097	41 097	41 097	17 836
Louisa	80 684	80 684	78 058	44 484
Nelson	148 809	129 207	129 207	95 755
(d) Hard hardwood volume				
Total	864 177	830 395	773 794	511 489
Albemarle	282 528	281 634	276 830	190 825
Fluvanna	87 864	85 143	67 772	39 780
Greene	57 151	57 151	57 151	23 968
Louisa	189 445	189 445	155 019	94 039
Nelson	247 189	217 022	217 022	162 877

6. Future population growth

Populations will likely continue to expand in the Thomas Jefferson Planning District. To examine the potential effects on forests we estimated the net effect that various levels of population growth might have on commercial forest area using the methods developed here. We increased the population density for individual plots and recalculated the probability of commercial timberland using Eq. (2). These values were then used to screen the survey data using Eq. (4).

Population growth is a spatially defined process with growth concentrated at the periphery of high density areas. We did not attempt to develop and apply a sophisticated model of urban and suburban expansion for this exercise; rather, we examined a simple model that expanded populations by an equal proportion across the entire study area. These projections therefore do not represent forecasts, but they do allow for a qualitative examination of the consequences of population growth.

Results of the population simulations are charted in Fig. 5, with timberland plotted against population (both are charted in terms of percentage change from their present values). The results show an approximately linear relationship between population growth

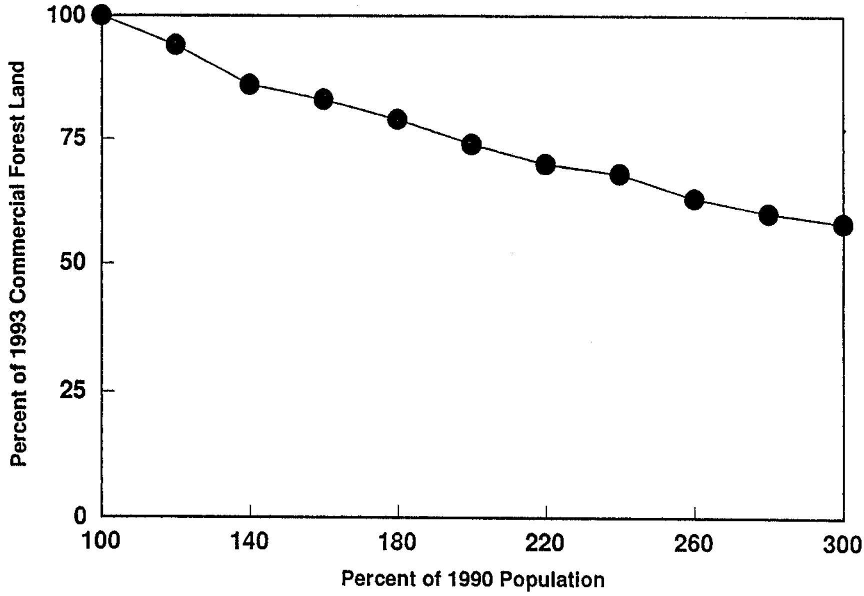

Fig. 5. Percent change in timberland as a function of change in population density.

and timberland declines in timberland area. For each 20% increment in population, timberland area drops by roughly 4%. As Fig. 3 indicates, a large share of timberland is in areas with a very low population density (the two right-most bars in Fig. 3). There is relatively little timberland area in the transition population densities of 20–70 psm. As a result, the existing estimate of timberland area may be fairly robust to moderate expansion in population density.

7. Conclusion

Population growth may influence forests and forestry in several direct and indirect ways. We have examined the net effect that population density may have on the availability of forests for timber production. While perhaps only a first approximation of these effects, our results indicate that changes at the urban–rural interface may have important influence on the future supply of timber. Because population data are so readily available in spatially referenced form (i.e. through the US Census Tiger/Line files), this approach may prove especially useful for examining the effects of suburbanization on timber production over broader areas.

We have tested for and estimated the relationship between population density and the potential for commercial forestry. The results indicate a continuous relationship, but also suggests some important thresholds. One is that the probability of forest management approaches zero at ca. 150 people psm. At 70 psm there is a 25% chance of commercial forestry. At ca. 45 psm the odds are 50 : 50 that commercial forestry will be practiced and at 20 psm there is a 75% chance. The implication is that a transition between rural and urban use of forests occurs between 20 and 70 psm, suggesting that future research should focus on understanding land use dynamics and resource management in this zone.

The results of this study indicate that raw estimates of timberland – based on physical criteria alone – may substantially overstate the availability of timber. We estimated that population effects reduced timberland area and growing stock volumes by roughly 40% from their measured values. While only a first approximation of the effects of population growth on forest lands, these results indicate that the effects can be substantial. Of course these results are developed for only a small area and would therefore benefit from replication in other areas. It would be useful to know whether these relationships hold generally. Do they, for example, differ in areas with different topography, landownership pattern, or relative resource values?

The study also illustrates the value of linking biophysical forest inventories with social data. This linkage could be improved by recording census block identifiers for each plot in a forest survey. This would both improve the precision of subsequent analyses and allow for direct screening of inventories without linkage to a GIS. More extensive study in this area could lead to significant improvements in our understanding of timber supply from private lands and the general expression of social phenomena on forested landscapes.

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